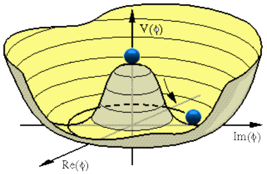
An Inclusive Search for H→WW at CDF

Matthew Herndon, University of Wisconsin Madison

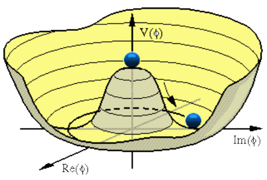
FNAL Theory Group Seminar, August 2009



Electroweak Symmetry Breaking

- An experimentalist's conception
- Consider the Electromagnetic and the Weak Forces
- Coupling at low energy: EM: ~α, Weak: ~$\alpha/(M_{W,Z})^2$
  - Fundamental difference in the coupling strengths at low energy, but apparently governed by the same dimensionless constant
  - Difference due to the massive nature of the W and Z bosons
- SM postulates a mechanism of electroweak symmetry breaking via the Higgs mechanism
  - Results in massive vector bosons and mass terms for the fermions
  - Directly testable by searching for the Higgs boson

A primary goal of the Tevatron and LHC



Electroweak Constraints

- Higgs couples strongly to massive particles
  - Introduces corrections to W and top masses - sensitivity to Higgs mass

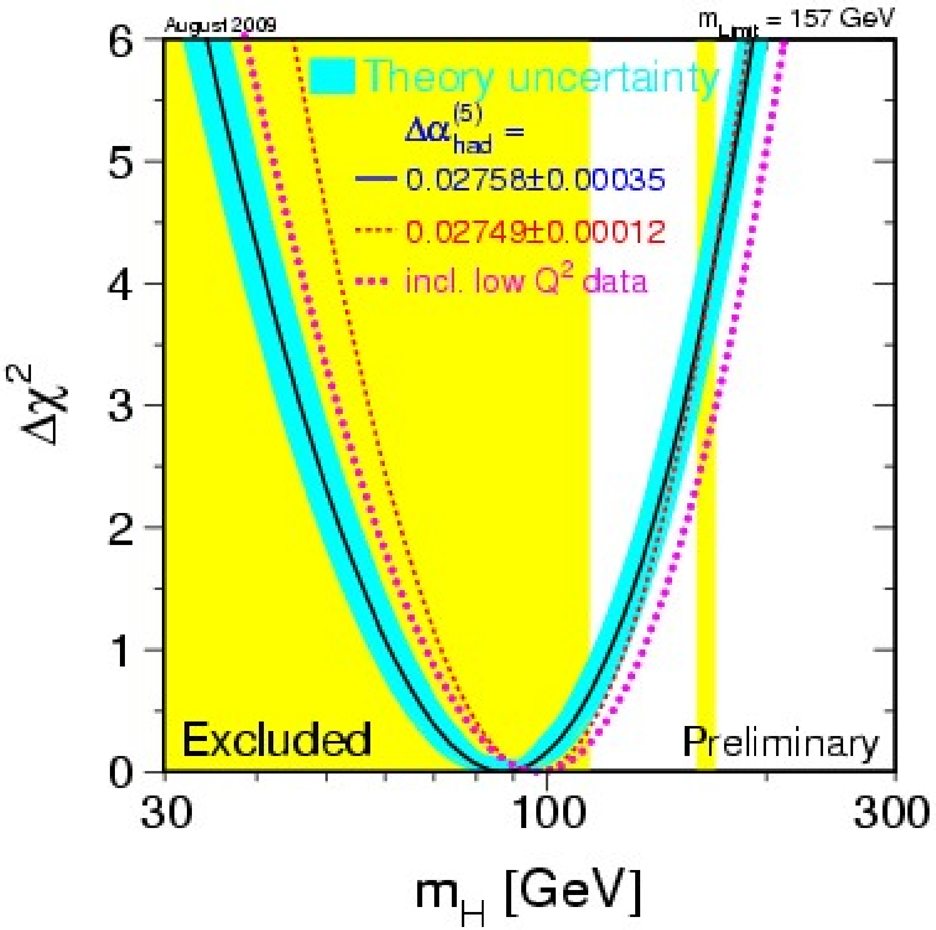
SM LEP Direct search:

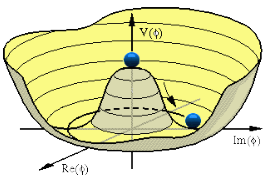
m_H > 114GeV

SM indirect constraint:

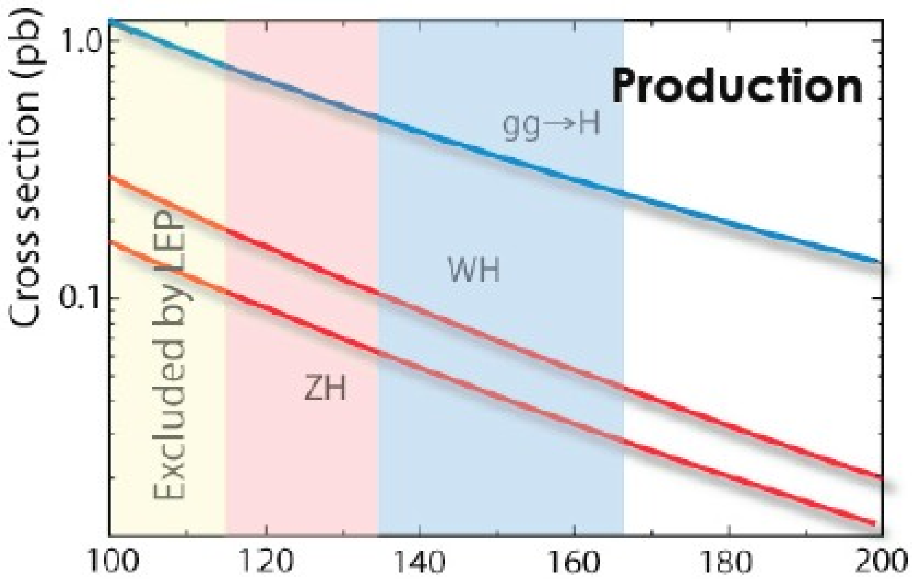
m_H < 157GeV @ 95% CL

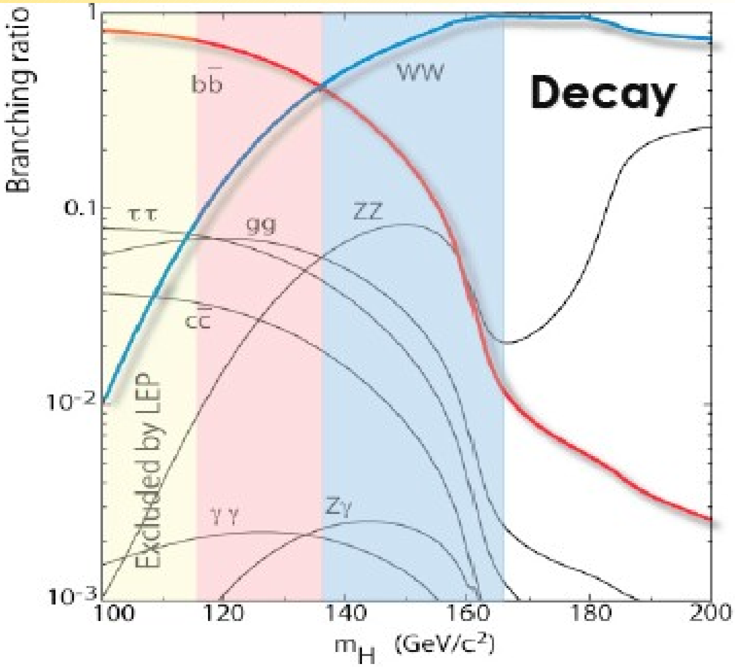
We know where to look!



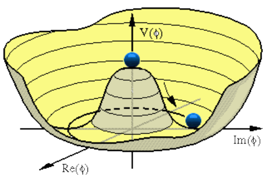


SM Higgs Production and Decay



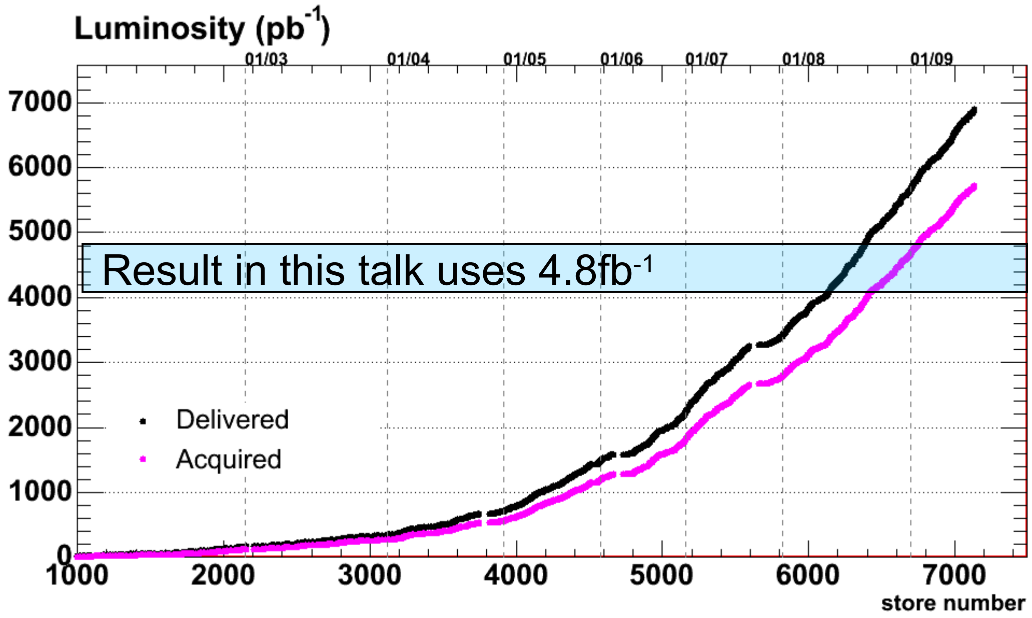


- High mass: H→WW→lνlν decay available
  - Take advantage of large gg→H production cross section
- Alternative production mechanisms
  - WH→WWW, ZH→ZWW, VBF: qq→Hqq->WWjj
  - Significant contribution in events with 1, 2 or more jets and same sign events



Colliders and Experiments

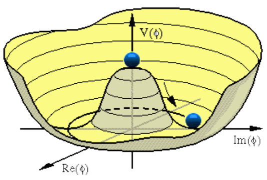
- Tevatron: 2TeV $p\bar{p}$ collider with two general purpose detectors:
- CDF properties
  - Excellent lepton Id
  - Good calorimeters for jet and MET reconstruction
  - Excellent silicon detector for b jet identification (top rejection)
  - Higgs analysis uses full capabilities of the detectors



Given a SM Higgs

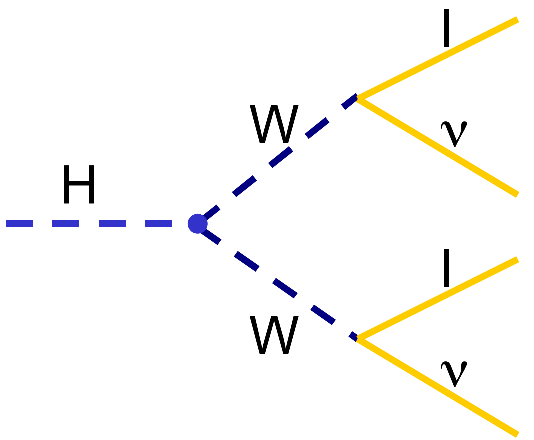
Tevatron: Higgs mass exclusions or evidence

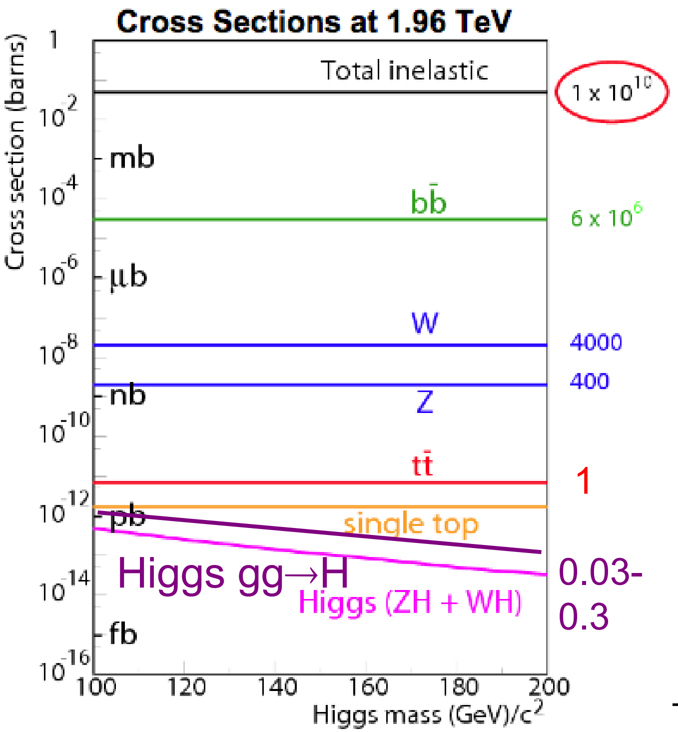
High mass Higgs the most interesting with current dataset



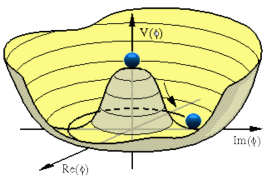
Tools: Triggers and Leptons

- Extract handful of Higgs events from a background 11 orders of magnitudes larger
- Higgs couples, decays to heavy particles
- Primary triggers: High p_T e and μ
  - Triggers upgraded to use previously non triggerable areas of the muon system
- Lepton Id
  - Optimize lepton Id on large samples of W, Z bosons
  - Lepton Id and trigger performance calibrated to high precession on Z samples



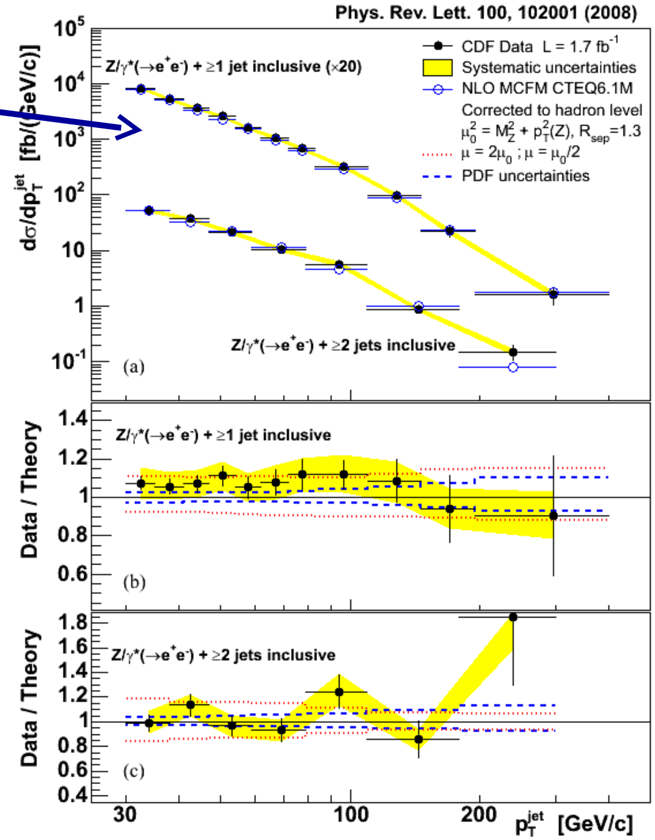


Maximizing Higgs acceptance

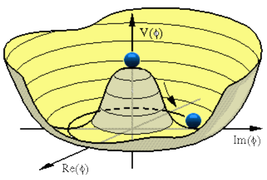


Tools: Backgrounds

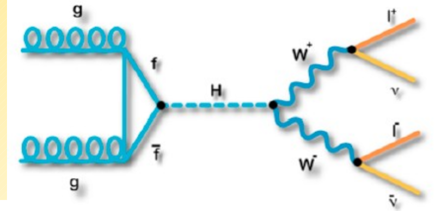
- SM processes create a variety backgrounds to Higgs detection
- Discovery analyses: WW, WZ, ZZ, from run 1 - top pairs
- Total and differential cross section measurements
  - QCD dijets, W+jets, Z(γ*)+jets
- Critical to Higgs
  - Some backgrounds cannot be predicted using MC. W+jets with a fake lepton
  - Constrain background predictions
  - Testing ground for tools and techniques
  - Control regions



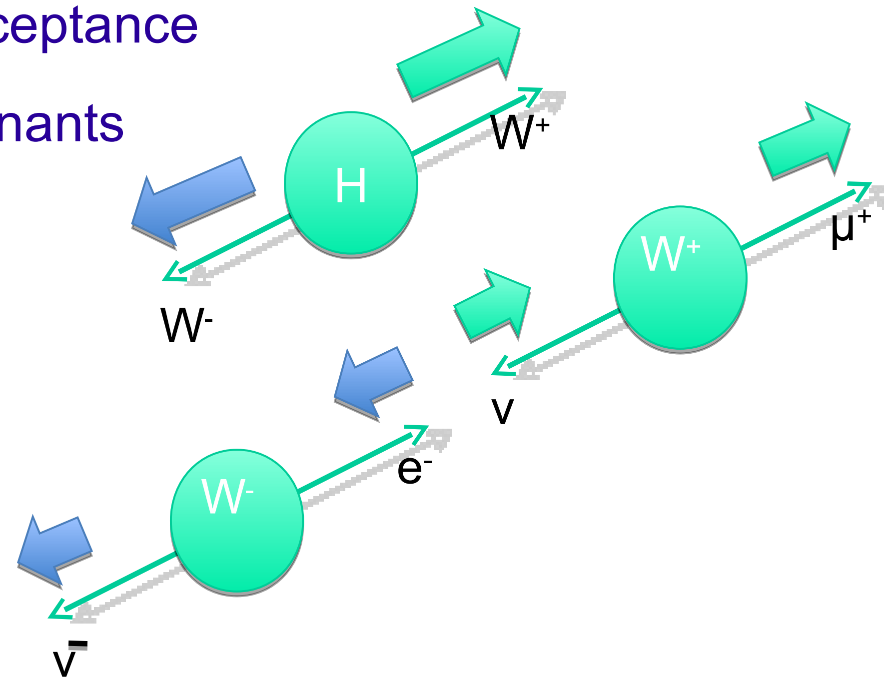
Higgs search built on a foundation of the entire collider physics program

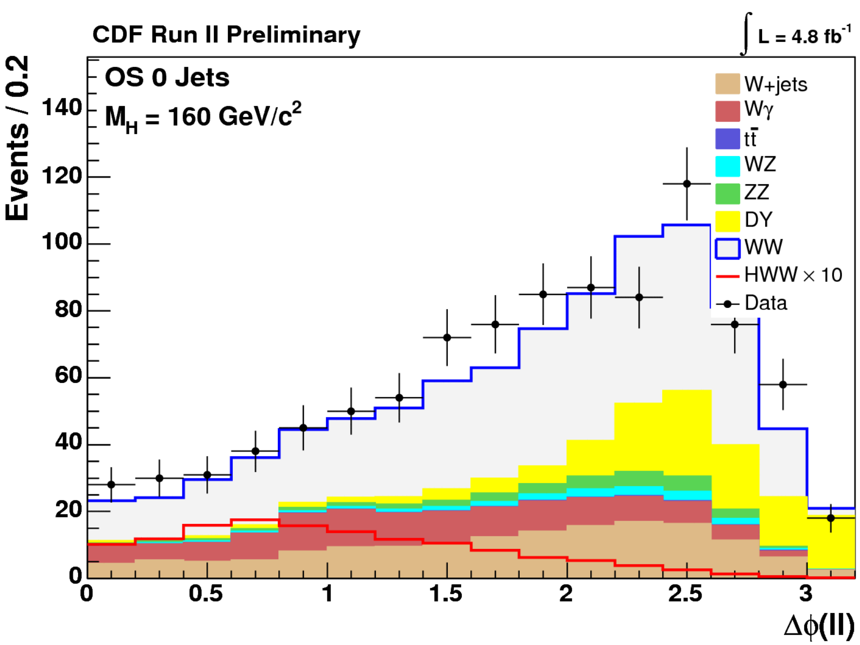


SM Higgs: H→WW

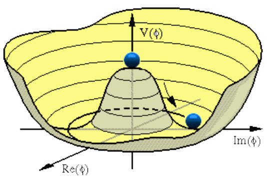


- $H \to WW \to l\nu l\nu$ - signature: Two high p_T leptons and MET
  - Primary backgrounds: WW and top in di-lepton decay channel
  - Key issue: Maximizing signal acceptance
  - Excellent physics based discriminants

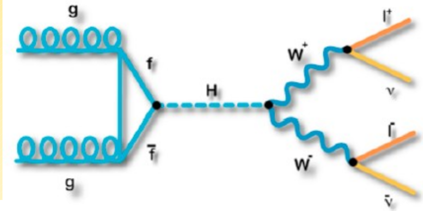




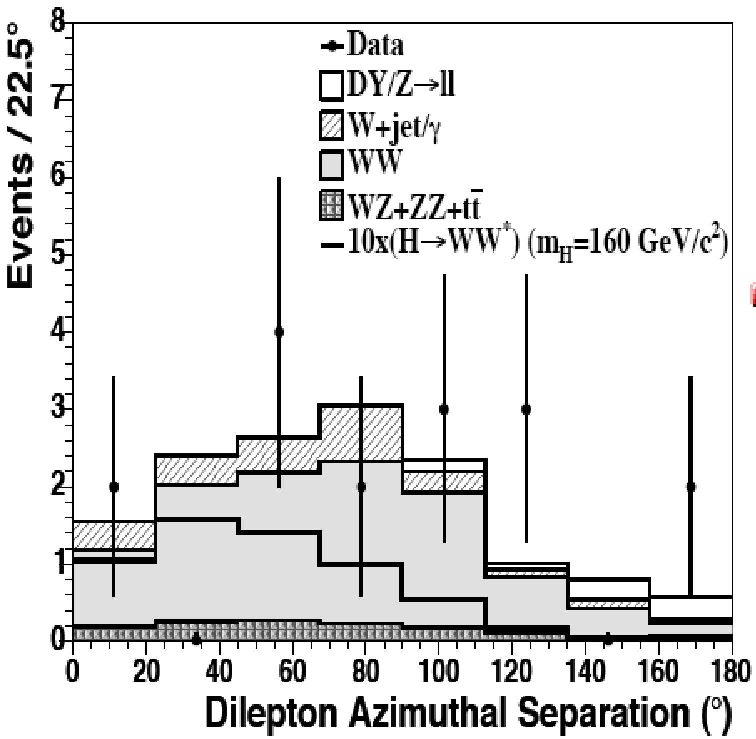
Spin correlation: Charged leptons go in the same direction



H→WW: Δφ Analysis



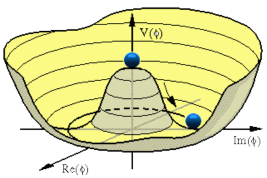
- Initial analysis: PRL 97, 081802 (2006)
  - gg → H production only
  - Purely based on signal vs. background discrimination of Δφ variable
  - Used standard CDF high p_T lepton Id



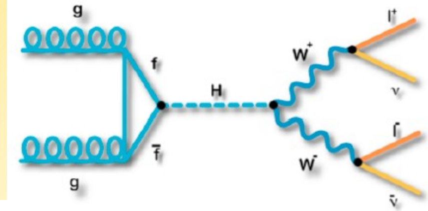
Results: mH = 160GeV : 95%CL Limits/SM

Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF: Δφ	0.36	0.58	8.9	8.2

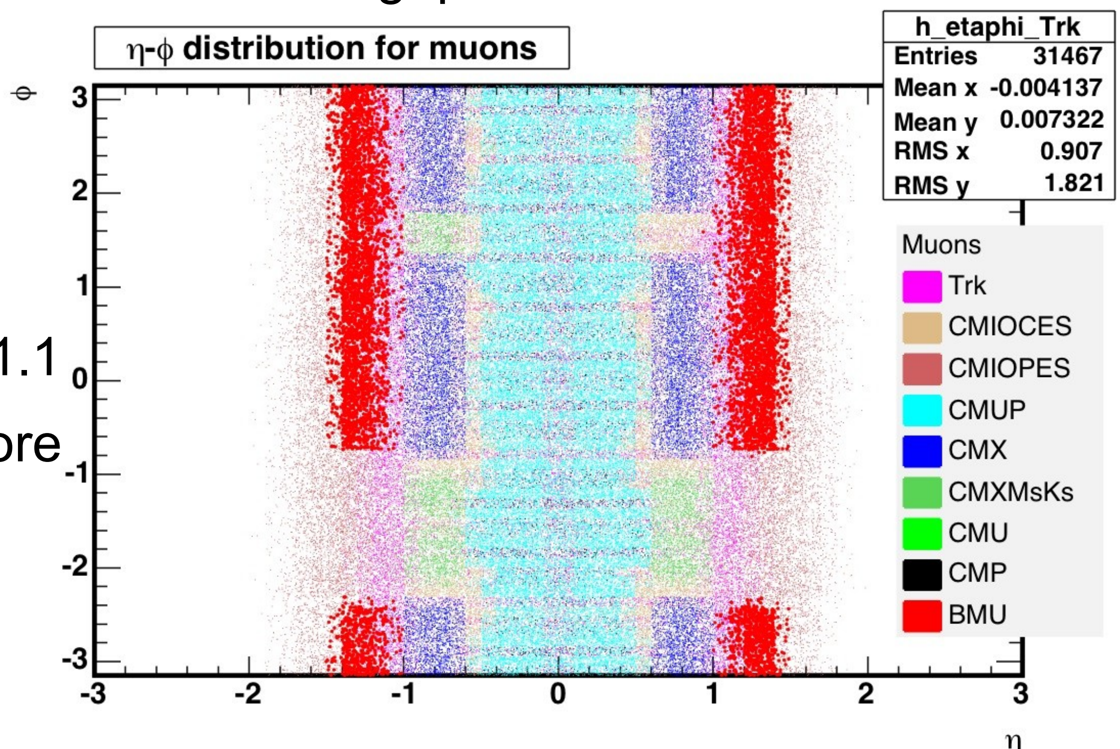
- Compared to current $4.8fb^{-1}$ analysis
  - Higgs acceptance improved: ~x3.8
  - 3 years, 15 people, 8FTE, 1 paper
  - Interestingly acceptance improvement and new data almost accounts for current sensitivity: Naive expectation: 1.3xSM



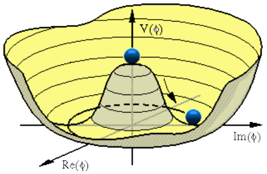
H→WW Improvements



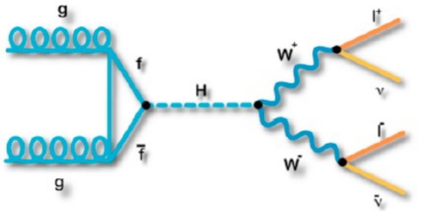
- Lepton acceptance: x2.5 effective statistics
  - Based on lepton selection of WZ and ZZ discovery analyses: x2.2
    - Electrons in calorimeter gaps
    - Muons in forward region and detector gaps
  - Further improvements
    - New muon triggers in partially instrumented regions (pioneered in single top analysis): x1.1
    - Electron likelihood, more efficient for same fake rate: x1.1



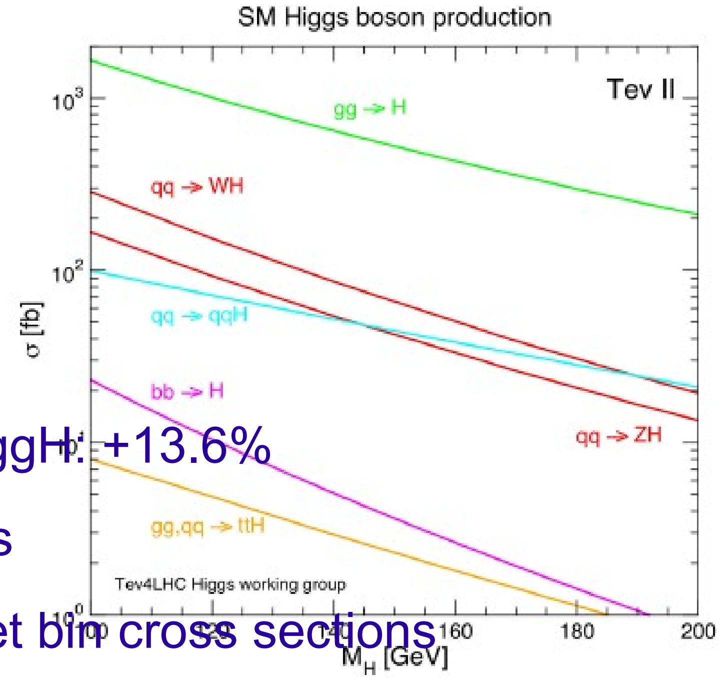
- 8 μ , 2 e and 1 e/μ type
- Performance validated in 31 DY and 14 Z→ττ control regions



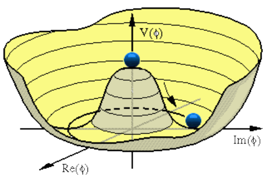
H→WW Improvements



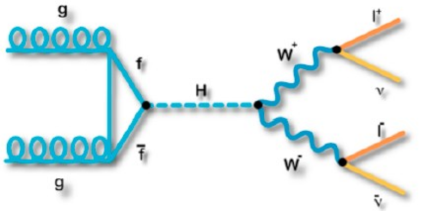
- Higgs production processes: x1.55 effective statistics
  - WH: +24%
  - ZH: +8.6%
  - VBF: +8.8%
  - Same sign region for WH and ZH
  - 2+ Jets region for all processes including ggH: +13.6%
  - Required re-optimization of analysis in jet bins
  - Some sensitivity lost to theory errors on per jet bin cross sections



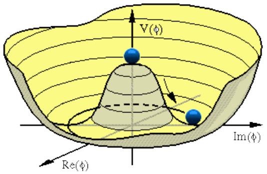
- Low dilepton mass region: +3.8%
- Required understanding of new control regions and backgrounds as a function of jet multiplicity



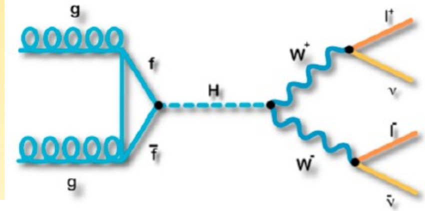
H→WW Improvements



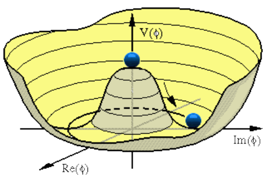
- Multivariate discriminants
  - Neural Net: x1.2
  - Matrix Element likelihood ratio: x1.2
- Final analysis combining above: x1.3 sensitivity
  - Signals and backgrounds categorized by lepton quality and jet multiplicity
  - Specific backgrounds and types of signal occur in each jet multiplicity bin
  - Fake lepton background primarily in categories with low lepton quality
  - Simplified identification of physics based discriminating variables
  - Matrix elements used in 0 jet bin only
  - Adds 10% over use of NN or Matrix Element alone
- Requires extensive validation



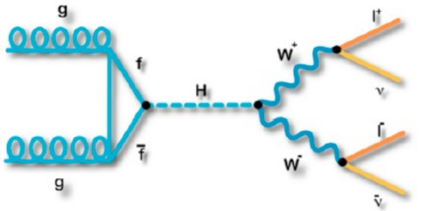
Multivariate Analysis



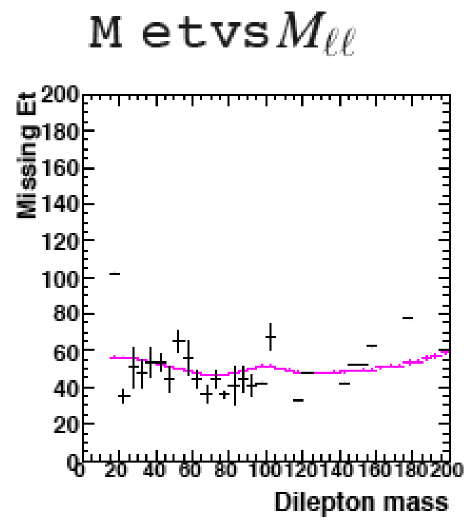
- Validation of multivariate discriminants
  - This procedure is standard within the Higgs group
- Technical tests
  - Tests for overtraining
  - Stability of various trainings and stability across adjacent mass points
- Optimal variables
  - Examine correlation of variables to NN output. Only keep most significant. Typically order 10 variables.
  - Examine 2D correlations between variables and identify where there is strong discrimination between signal and background.

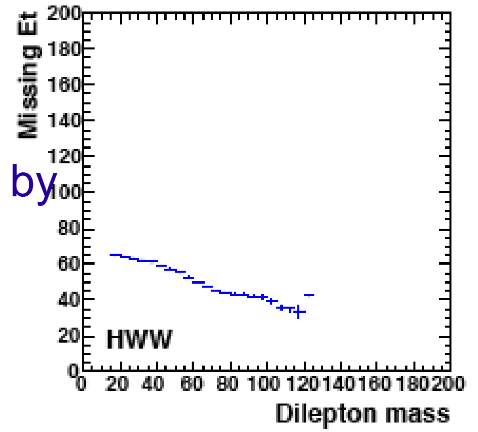


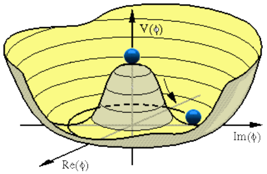
Multivariate Analysis



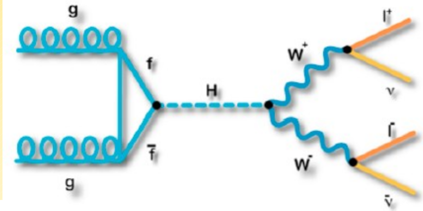
- Variable modeling: typically 10 NN and 10 kinematic
  - MC vs data in signal and relevant control regions
  - Also check 2D profile plots
  - With NN divide plots into signal like and background like regions and check modeling in both regions separately
- These checks have led to discarding variables and systematic uncertainty studies
  - Angle between jets in 2 jet events not well modeled. Not surprising since primary MC is Pythia
    - Total vector sum Jet Et is fine
  - N Jet distribution in DY poorly modeled. Systematic check done by reweighing DY MC to correct distribution





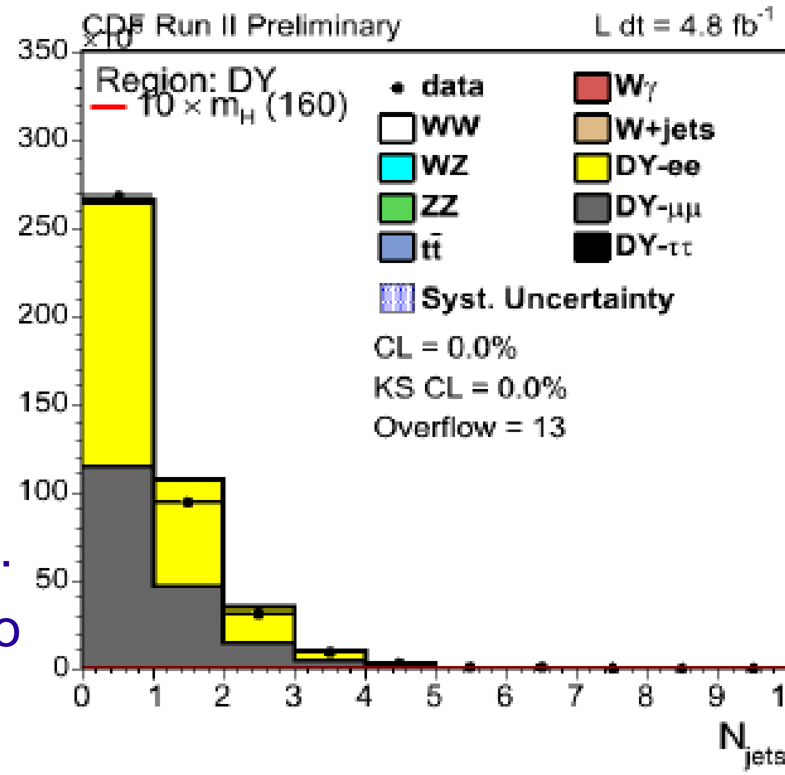


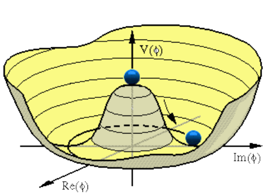
Multivariate Analysis



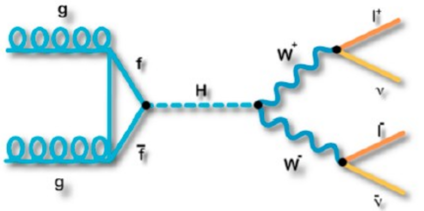
Check final NN output in signal and control regions

- Systematic uncertainties
  - Check that NN output is not extremely susceptible to systematic effects that change shapes
  - Jet energy scale
  - Lepton fake rate vs. pt
  - Higgs scale and pdf variations (NNLO). Now checked in jet multiplicity bins also
  - DY reweighing to match data
  - WW background scale, pdf (NNLO tools would be useful)
  - gluon fusion production fraction (in progress, first look using histograms from DO indicated that this is not a severe effect).



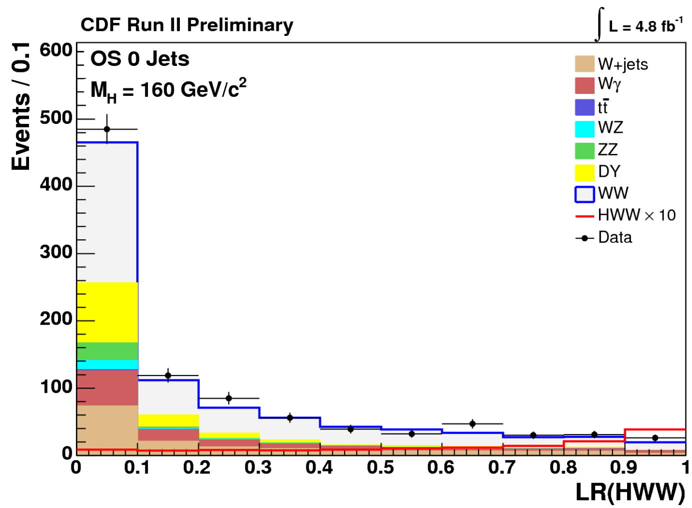


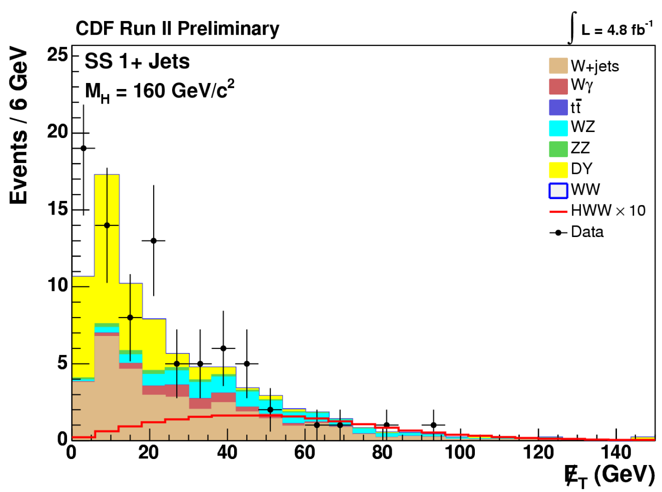
SM Higgs: H→WW

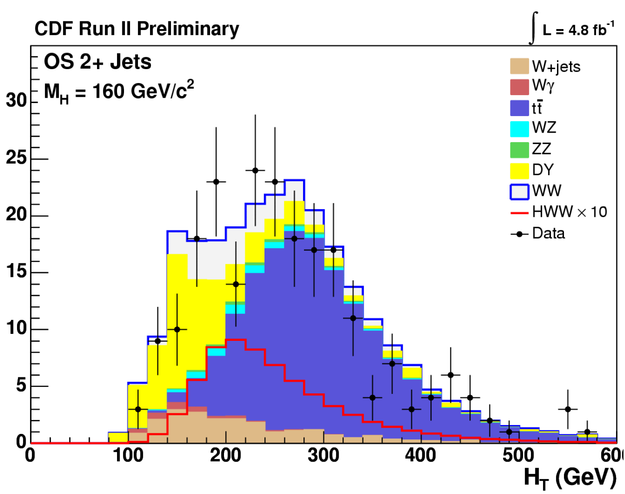


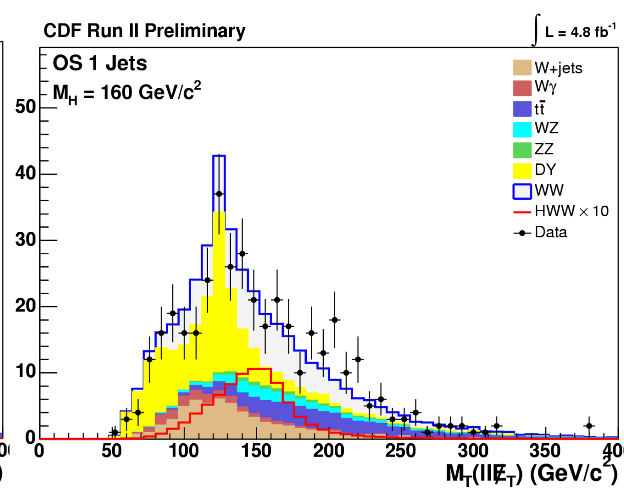
- Inclusive H→WW analysis: lνlν MET – signature

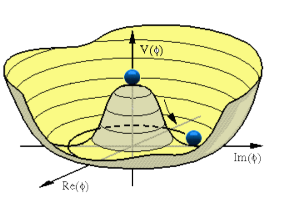
Channel	Signal	Primary background	Primary discriminants
0 Jets	gg→H	WW, DY	Δφ/R,MET,ME
1 Jet	gg→H, VH, VBF	WW, DY	Δφ/R,MET,m_{TH}
2+ Jets	gg→H, VH, VBF	Top dilepton	MET,HT,m_{TH}
1+ Jets SS lepton	VH	W+Jets	Good lepton ID, MET
Low mll	gg→H	γ conv.	Lepton pT



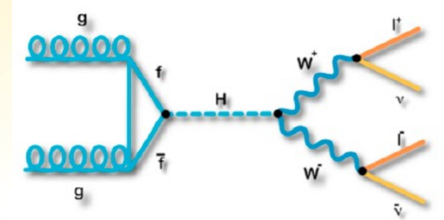




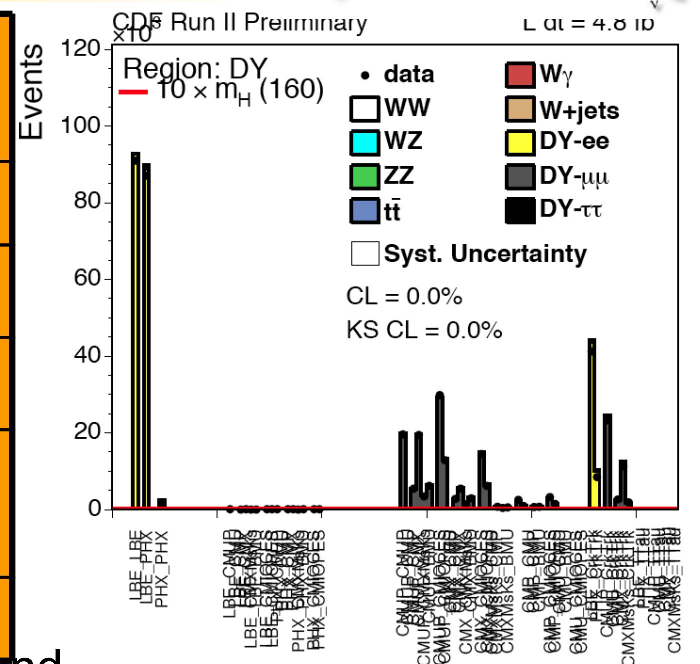




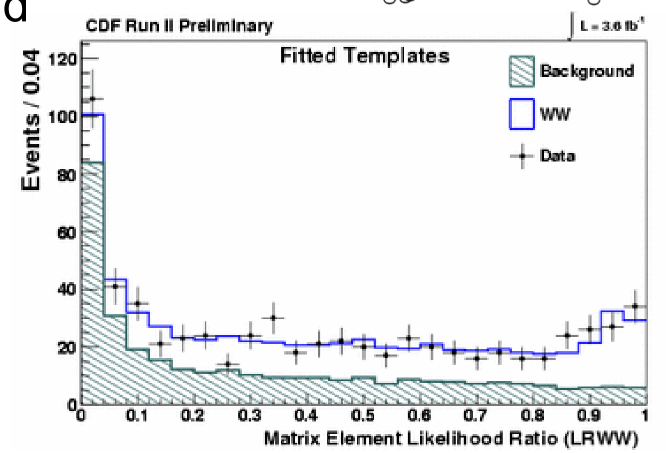
Control Regions

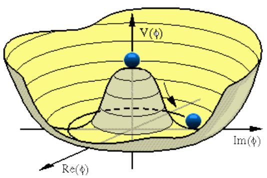


Channel	Signal	Primary background	Primary discriminants
0 Jets	gg→H	WW, DY	Δφ/R,MET,ME
1 Jet	gg→H, VH, VBF	WW, DY	Δφ/R,MET,m_{TH}
2+ Jets	gg→H, VH, VBF	Top dilepton	MET,HT,m_{TH}
1+ Jets SS lepton	VH	W+Jets	Good lepton ID, MET
Low mll	gg→H	γ conv.	Lepton pT

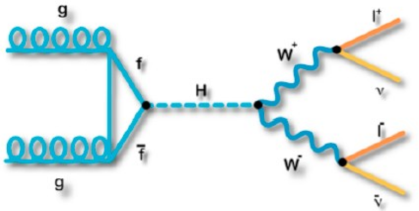


- At least one control region for every primary background
- Control regions
  - Low MET: Understand DY, lepton Id efficiencies
  - Large MET aligned along jet of lepton: False MET
  - SS: W+false leptons (0 jet bin only)
  - High WW ME likelihood: Measure WW cross section
  - b tagged jets, top dilepton: Measure ttbar cross section
  - Low dilepton mass low MET OS and SS: Photon conversion backgrounds

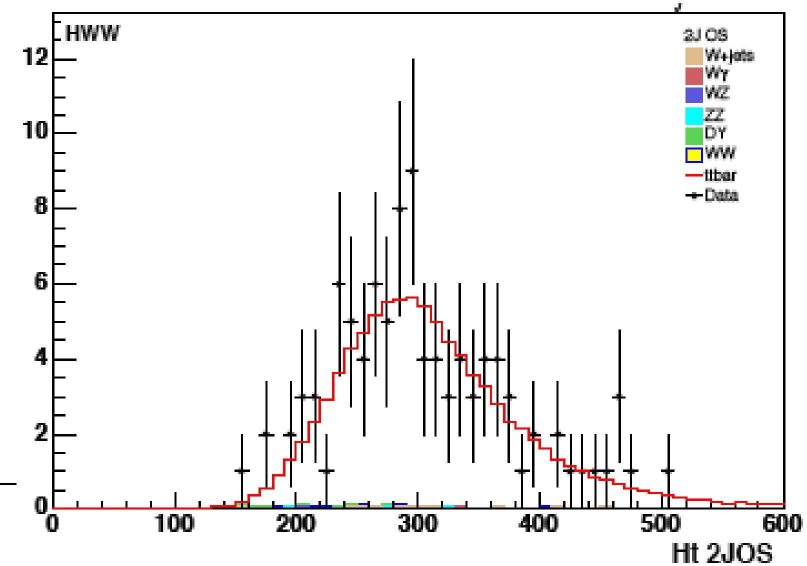


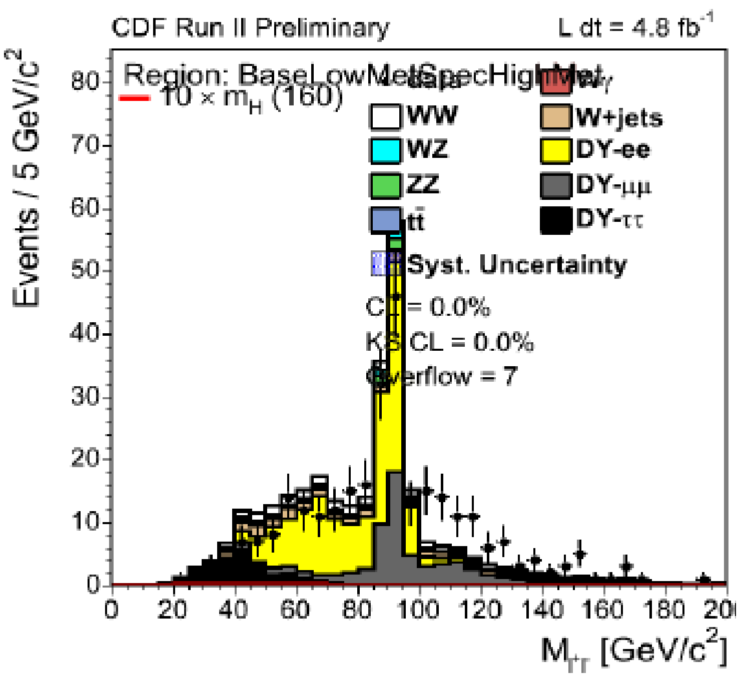


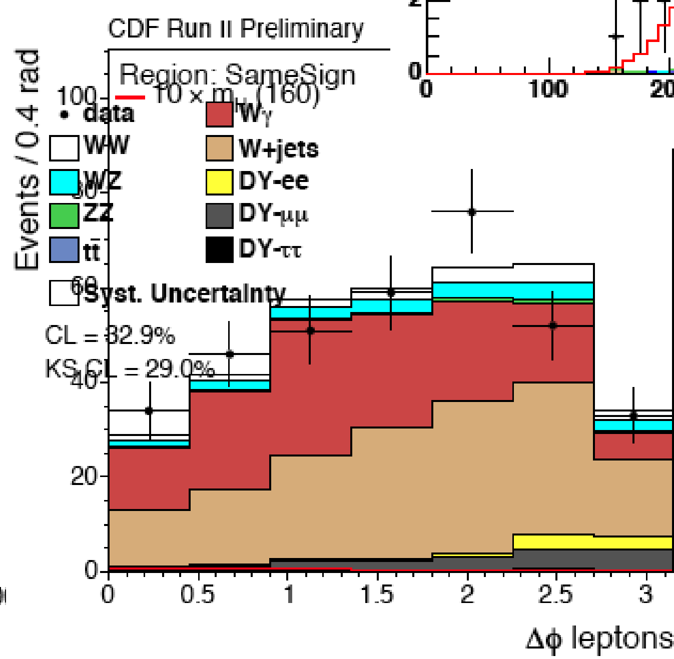
Control Regions

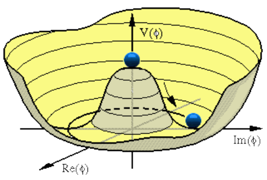


- Control regions, further examples
  - Large MET aligned along jet of lepton: False MET region
  - SS: W+false leptons region
  - b tagged jets: top dilepton region

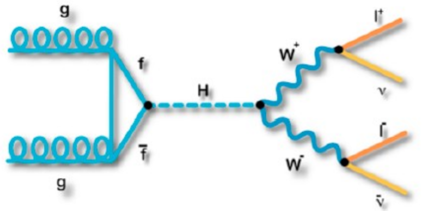


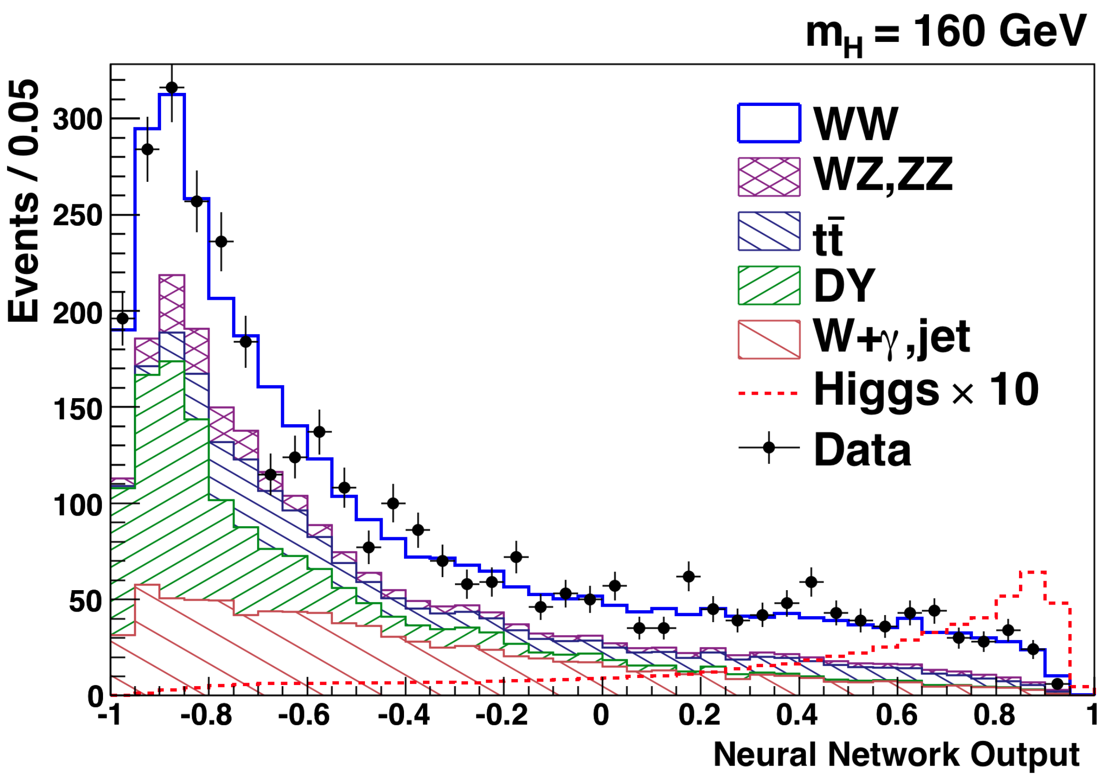






H→WW Result



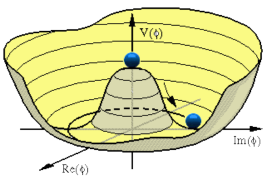


CDF Run II Preliminary	$\int \mathcal{L} = 4.8\ \mathrm{fb}^{-1}$		
$M_H = 165\ \mathrm{GeV}/c^2$			
$t\bar{t}$	196	±	32
DY	342	±	61
WW	605	±	65
WZ	54.8	±	7.5
ZZ	42.3	±	5.8
W+jets	278	±	70
$W\gamma$	191	±	27
Total Background	1710	±	140
$gg \to H$	22.3	±	4.8
WH	4.38	±	0.57
ZH	1.59	±	0.21
VBF	1.61	±	0.26
Total Signal	29.8	±	5.1
Data	1733		

High Mass

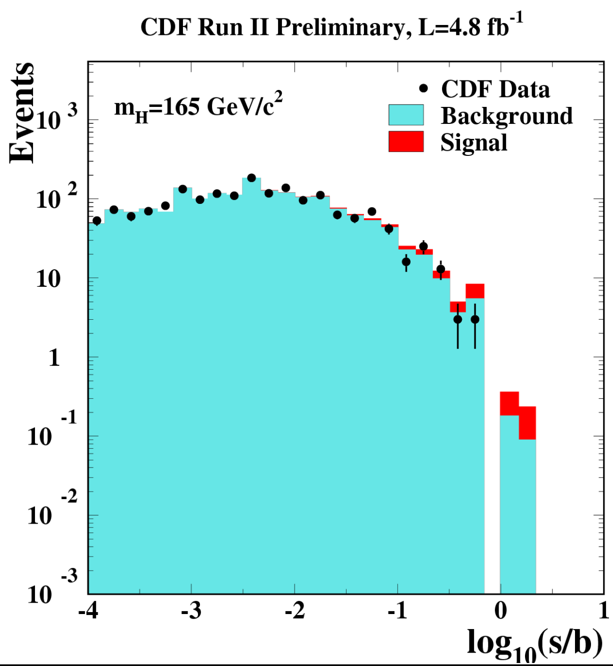
Approaching SM sensitivity!

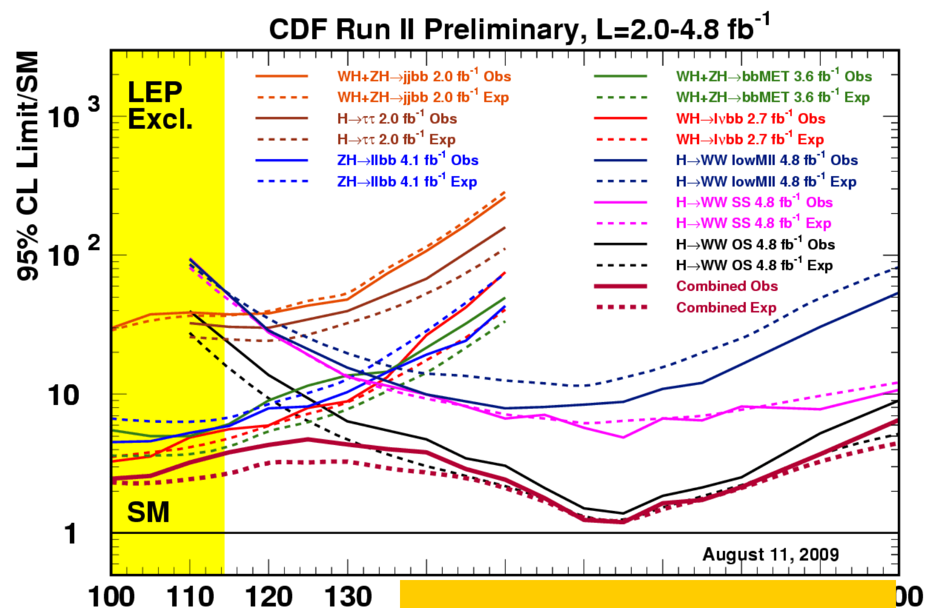
30 Higgs Events!



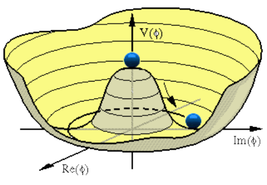
Combined Limits

- Limit calculation and combination
  - Combination necessary in H→WW similar to the full CDF combination
  - Using Bayesian methodology.
  - Incorporate systematic uncertainties using pseudo-experiments (shape and rate included) (correlations taken into account between channels)
  - Backgrounds can be constrained in the fit

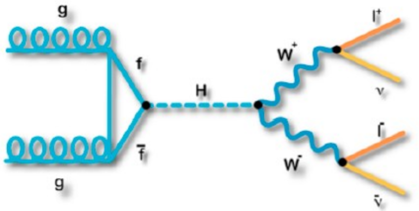




Exp. 2.5 @ 115



H→WW Some Details



- Previous NNLL cross section: S. Catani, D. de Florian, M. Grazzini, and P. Nason, JHEP 07, 028 (2003), hep-ph/0306211 CTEQ5L
  - Include two loop EW diagrams: U. Aglietta, B. Bonciani, G. Degrassi, and A. Vivini (2006), hep-ph/0610033.
  - 2009 MSTW PDFs — Martin Sterling Thorne Watt hep-ph/0901.0002
- Integrated together into the latest state of the art predictions
  - Latest gluon PDF, full treatment of EW contribution, better treatment of b quark masses

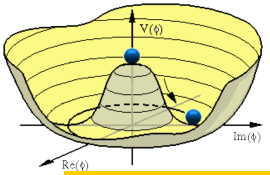
    C Anastasiou, R Boughezal, F Petriello, hep-ph/0811.3458

    D. de Florian, M. Grazzini, hep-ph/0901.2427 hep-ph/0905.3529
- Example systematic table
  - Rates and shapes considered
  - Shape: Scale variations (in jet bins), ISR, gluon pdf, Pythia vs. NNL0 kinematics, DY pt distribution, jet energy scale, lepton fake rate shapes: for signal and backgrounds. Included in limit setting if significant.

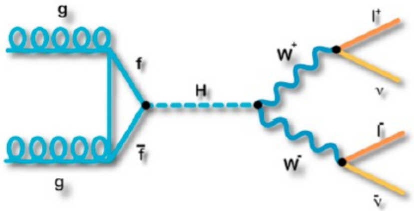
CDF: $H \to WW \to \ell^{\pm}\ell'^{\mp} + 0$ Jets Analysis

Uncertainty Source	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet	$gg \to H$	WH	ZH	VBF
Cross Section											
Scale								10.9%			
PDF Model								5.1%			
Total	*10.0%*	*10.0%*	*10.0%*	15.0%	5.0%	10.0%		12.0%			
Acceptance											
Scale (leptons)								2.5%			
Scale (jets)								4.6%			
PDF Model (leptons)	1.9%	2.7%	2.7%	2.1%	4.1%	2.2%		1.5%			
PDF Model (jets)								0.9%			
Higher-order Diagrams	**5.5%**	**10.0%**	**10.0%**	10.0%	**5.0%**	**10.0%**					
Missing Et Modeling	1.0%	1.0%	1.0%	1.0%	20.0%	1.0%		1.0%			
Conversion Modeling						20.0%					
Jet Fake Rates											
(Low S/B)							21.5%				
(High S/B)							27.7%				
MC Run Dependence	3.9%			4.5%		4.5%		3.7%			
Lepton ID Efficiencies	2.0%	1.7%	2.0%	2.0%	1.9%	1.4%		1.9%			
Trigger Efficiencies	2.1%	2.1%	2.1%	2.0%	3.4%	7.0%		3.3%			
Luminosity	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%		5.9%			

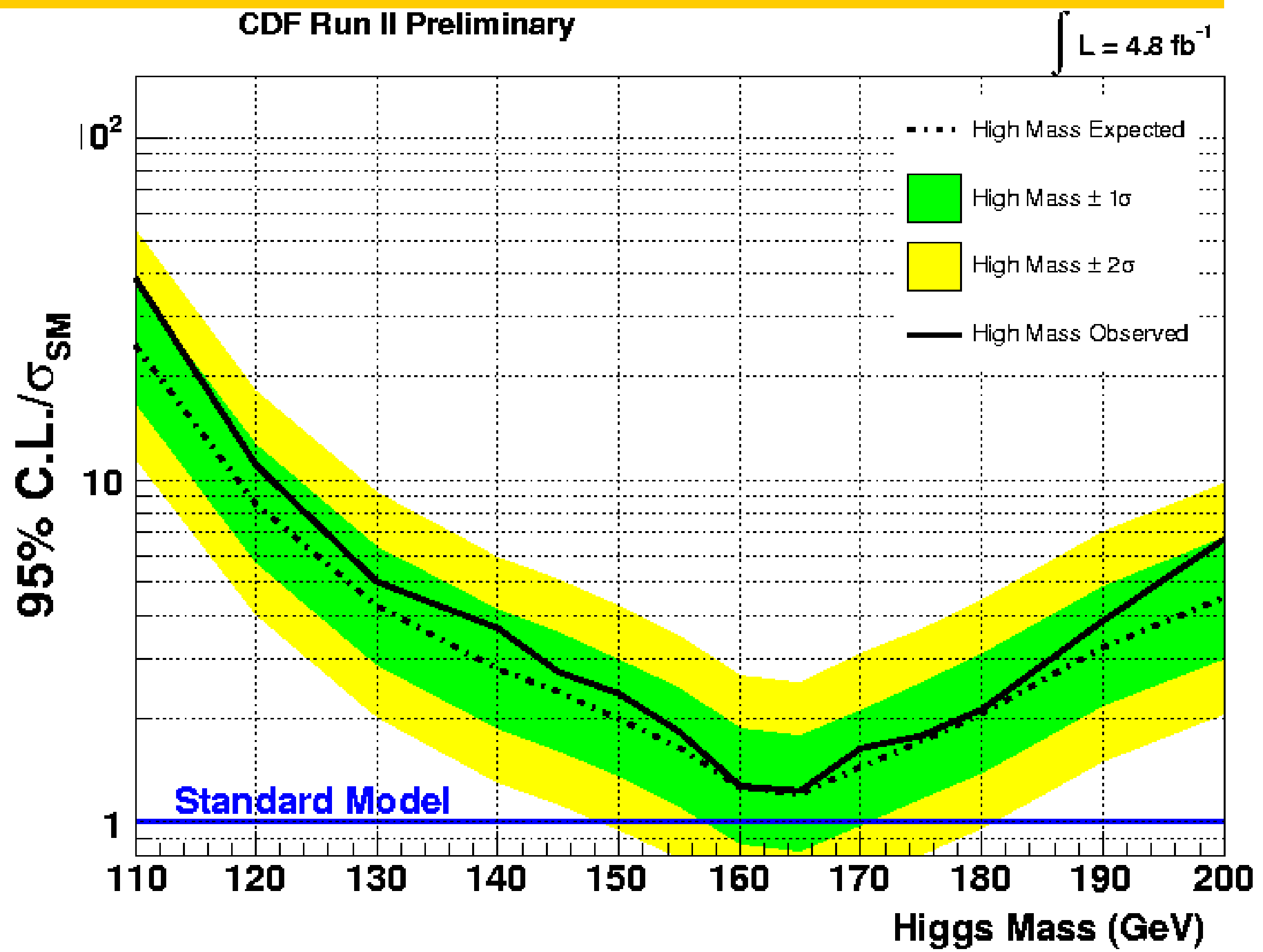
Treatment developed jointly by CDF and DØ



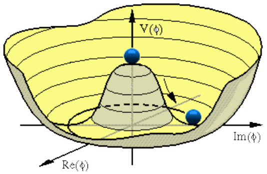
H→WW Result



Exp. 1.26 @ 160, 1.21 @ 165, 1.45 @ 170 GeV

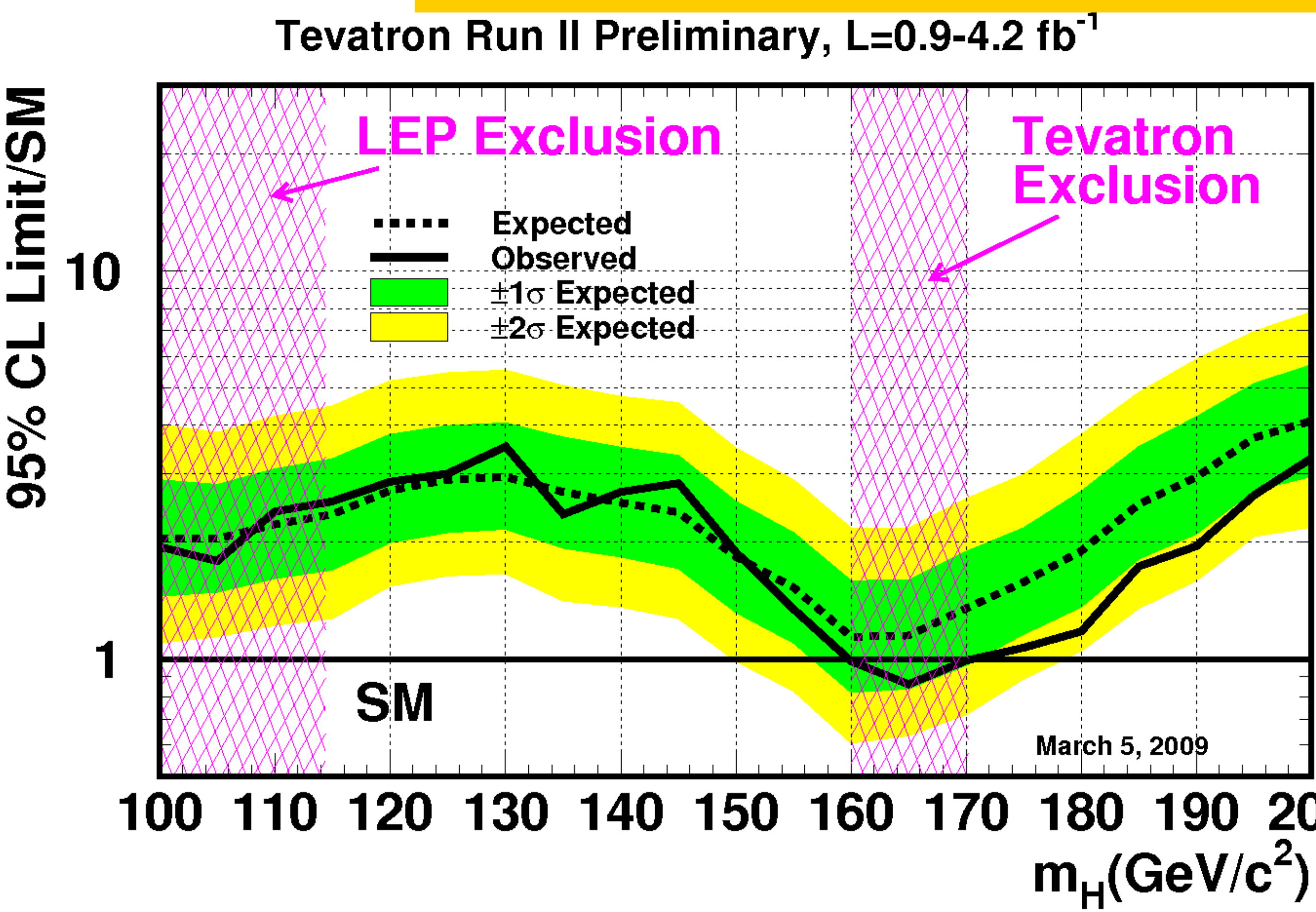


Obs. 1.27 @ 160, 1.23 @ 165, 1.64 @ 170



Tevatron Higgs Combination

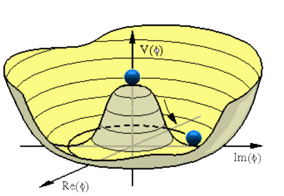
Exp. 1.1 @ 160/165, 1.4 @ 170 GeV



Signal yield (events)	Background yield (events)	Data
0.028	0.017	0
0.073	0.060	0
0.918	1.065	1
0.598	0.987	0
3.14	7.84	4
1.38	5.38	3
4.61	25.0	26

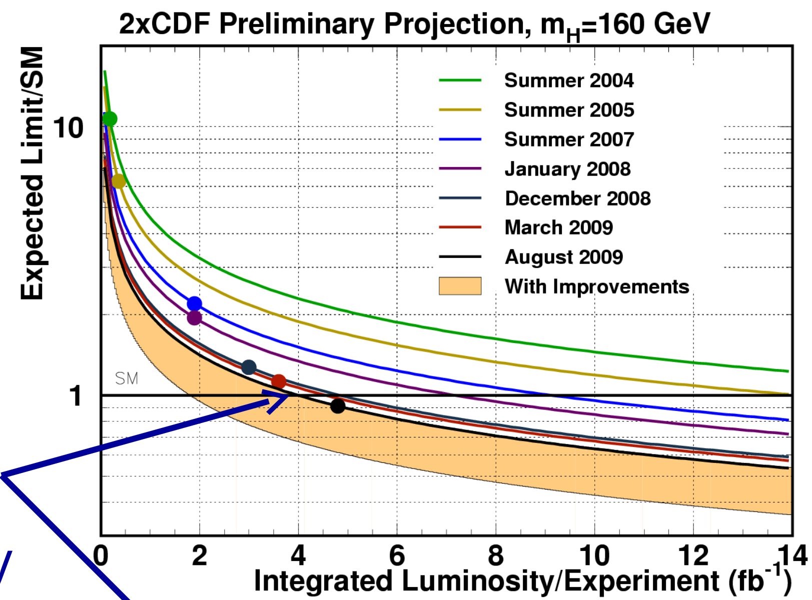
Exp. 2.4 @ 115

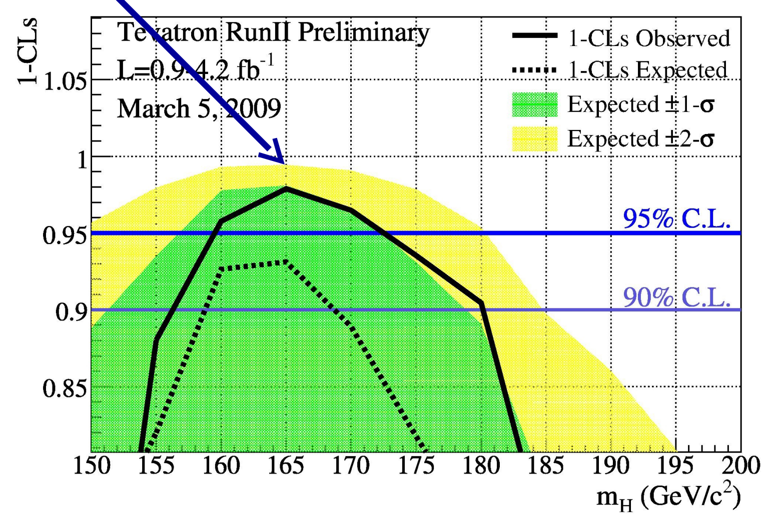
Obs. 0.99 @ 160/170, 0.86 @ 165 GeV

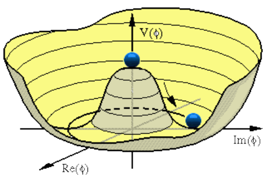


Projections

- Goals for increased sensitivity achieved
  - Goals set after 2007 Lepton Photon conference
  - First stage target was sensitivity for possible high mass Tevatron exclusion
  - Second stage goals: target is CDF only exclusion or large Tevatron exclusion in progress
    - Trileptons
    - Lower missing et
    - Tau channels
    - Overlapping leptons

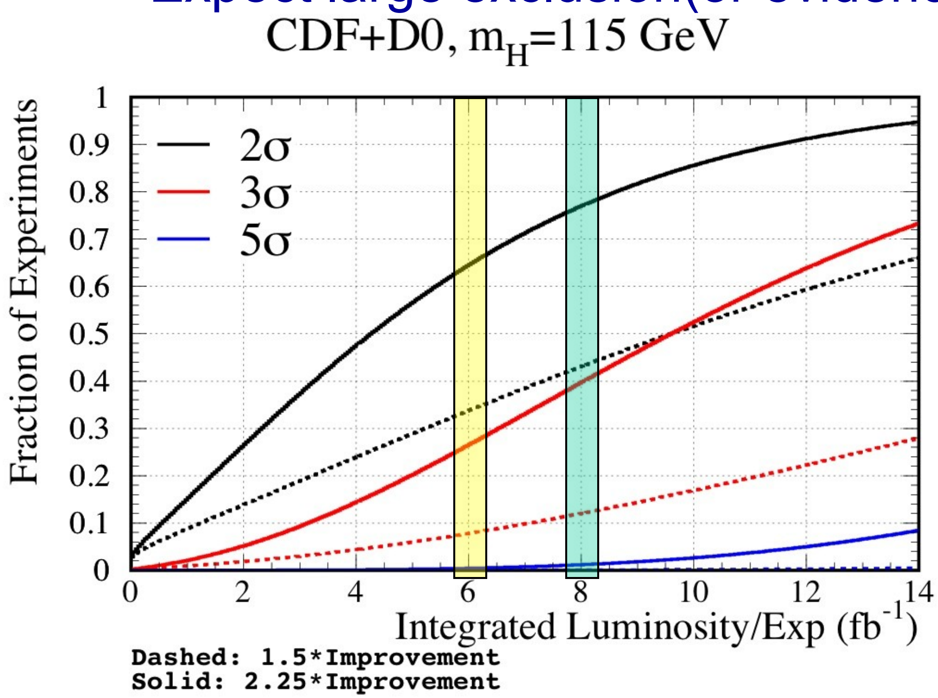


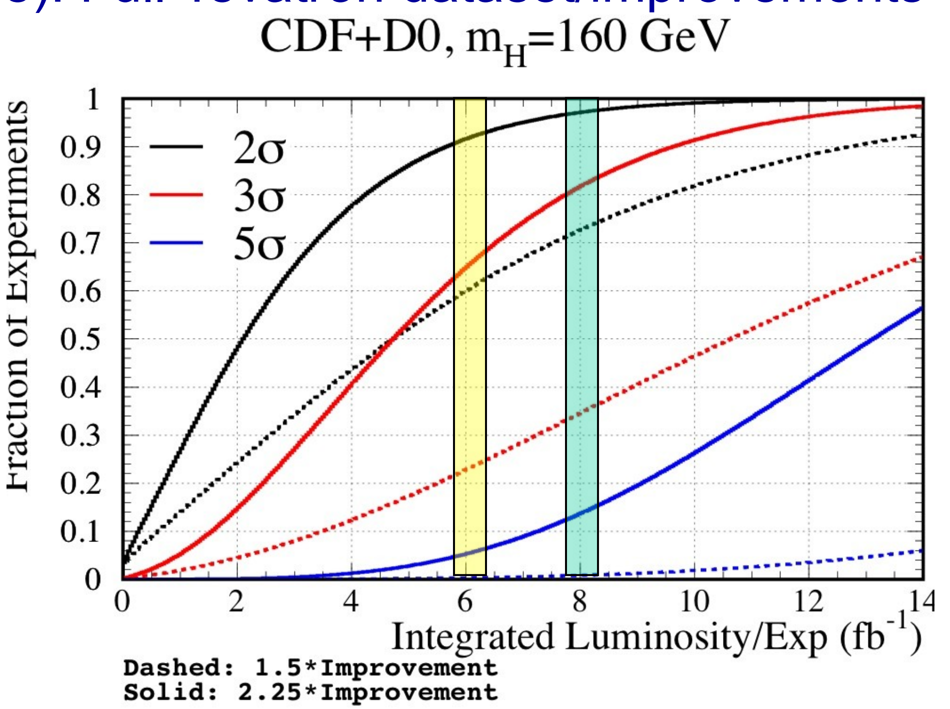


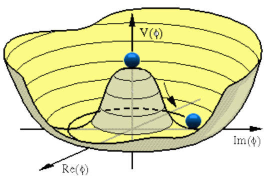


Discovery

- Discovery projections: chance of 3σ or 5σ discovery
  - Two factors of 1.5 improvements examined relative to summer Lepton Photon 2007 analyses, low and high mass
  - First 1.5 factor achieved for summer ICHEP 2008 analysis
  - Result: exclusion at m_H = 170 GeV. Already extended to 160-170 GeV
  - Expect large exclusion(or evidence): Full Tevatron dataset/improvements



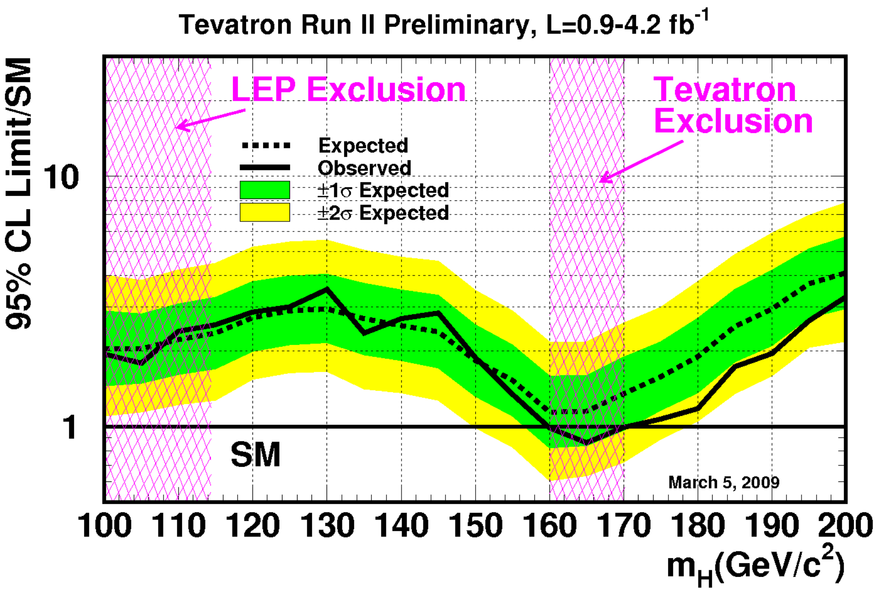




Conclusions

- The Higgs boson search is in its most exciting era ever
  - The Tevatron experiments have achieved sensitivity to the SM Higgs boson production cross section
  - CDF will reach sensitivity for single experiment exclusion soon

- We exclude at 95% C.L. the production of a SM Higgs boson of 160-170 GeV
  - Expect large exclusion, or evidence, with full Tevatron data set and improvements



SM Higgs Excluded: m_H = 160-170 GeV